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STRUCTURAL BASIS OF COMPRESSIVE EXTENSION AND SHEARING MECHANISMS IN THE CARPATHIAN FLYSCH ROCKS[1]

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According to uniaxial compression tests, variable fracturing, i.e. intragranular, intergranular or transgranular is strictly related to mineral composition and fabric of a rock. Basing on their analysis, deformation characteristics as well as the course of acoustic emission, it is possible to assess whether the resulting defects are caused by processes of extension, shearing or both of them.

Key words: rocks, structure, macrofractures, microfractures, deformation curve, acoustic emission, compression strenght

Uniaxial compressive tests (Pinińska, 1994, 1996, 1999) performed on more than a hundred type of rocks of different lithology and origin proved that in polymineral rocks, the character of structural contacts among grains, especially the position of high resistance grains, plays a significant role in the process of losing their stability.

If a rock is characterized by a *massive, regular and granular structure*, bound by a hard cementation, its main initial destabilization is achieved by brittle, intragranular fracturing stimulated by processes of extension of single grains. Consequently, brittle fracturing is initiated on the contact of high resistance grains, where great concentration of stresses occurs. According to the geological lithologenetic classifications, this kind of fracturing is characteristic for magmatic, sedimentary and exceptionally metamorphic rocks, where quartz grains appear locally in the direct adjacent position, while the intergranular space is filled with a hard, mostly siliceous cementation. Under loading,

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these structures remain stable for quite a long time, however their final split is rapid and they practically lose all their strength at the moment with any residual safety.

In the rocks, where *grains are either weak and irregular or scattered randomly in a weak cementation*, the fracturing process is intergranular, dominated by processes of shearing. The disintegration of structural bindings in rocks of such a construction is very slow due to the shearing resistance and uneven fracture surface. Despite the significant role of unstable fracturing processes, the residual strength after the final split of the structure is retained. This type of fracturing mechanism is characteristic for carbonate rocks, especially organogenic ones as well as weak clastic rocks with carbonate cementation, ferruginous-argillaceous ones and not crystallized metamorphic rocks of carbonate composition (Pinińska, 2001).

The meaning of quartz grains and their position as the initial focuses of fracturing under extension observed in different rocks in Poland is confirmed by the scientific research of granites from Westley (Brace and Bombolakis, 1963; Hori and Nemat-Nasser, 1985; Cundall and Fairhurst, 1986) and cristaline marbles (Olson and Peng, 1976).

The correlation between the structure and mechanisms of extension and the shearing noticed in various types of rocks in Poland is also supported by the detailed analysis of flysch sandstones whose mineral composition consists of more than 50% of quartz grains. Consistently, different participation of siliceous, carbonate and argillaceous cementation play the serious role in this correlation. Regardless of their monotonous composition, the mechanisms of initiation and accumulation of the fracturing processes show remarkable diversification due to their structural characteristics and the character of cementation.

The performed analysis of different flysch sandstone lithotypes concerned the characteristics of the rock fabric, relation between grains ("grain/grain" or "grain/cementation"), size of grains and their different geometry, presence of obstacles on the way of fissure development and dynamics of the fracturing processes under uniaxial compression.

Owing to the use of a stiff loading press it was possible to register the complete path of pre-critical and post-critical deformation. In the process of loading, the acoustic emission accompanying the deformation was also registered. Thus, the course of the fracturing process was simultaneously and fully controlled in time along two independent paths.

The research showed the oscillatory character of the flysch sandstones fracturing. Hysteresis loops of different energy, displayed on the deformation curve, revealed succeeding peaks of concentration and relaxation of stresses connected with formation of single defects in their structure. The oscillations appeared similarly to diagrams showing the course of acoustic emission accompanying the deformation process. Owing to tests performed with permanent control of the deformation velocity, the variable dynamics of defect accretion was registered in a time sequence similar to that of the acoustic emission course.

Data registered under the above investigation conditions serve as a useful source of information about the state of structure destabilization under loading (Pinińska, 1992). Particular results of the experiments conducted on sandstone flysch sediments indicate similarity to other rock media, mostly due to differences in the location of quartz grains and different cementation. Despite their relatively monotonous mineral composition, the fracturing processes progress with different dynamics, dependent on the characteristic features of heterogeneity of the rock fabric.

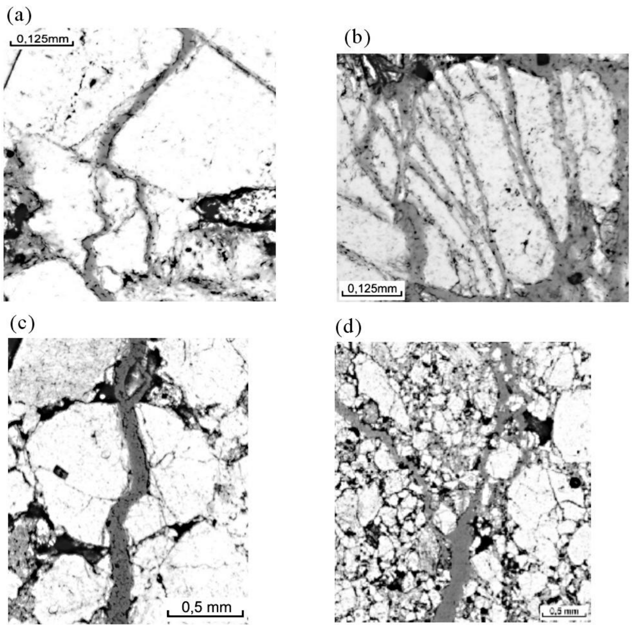

Fig. 1. Formation of initial fissures in flysch rocks: (a) – intragranular fracturing (flysch sandstone with siliceous cementation); (b) – concentration of local intragranular defects; (c) – development of a transgranular fissure (flysch sandstone of a compact structure and carbonaceus cementation); (d) – intergranular fracturing and development of a fissure with displacement (sandstone of a dispersed structure and siliceous-argillaceous-ferruginous cementation)

The shape and character of prefailure and postfailure structural defects are clearly visible on fixed thin plates sections. According to their analysis, in flysch sandstones as well as in other rock media of massive structures and containing quartz grains, the direct contact with the most resistant quartz grains results in concentration of stress at this point and destroys these grains in the first place. The focuses of fracturing are created in the consequence of extension processes like intragranular separation of certain grains. Such a situation can be observed on the example of sandstones with siliceous cementation from Kobyle (Fig. 1a), where local focuses of the fracturing concentrate in quartz grains, and the resistant siliceous cementation forbids transmission of the defects beyond its area. The appearing of the critical number of the local fracturings (Fig. 1b) results in global loss of resistance due to the development of a transgranular fissure (Fig. 1c).

If the grains are not in the adjacent position but are separated by a low resistance cementation, e.g. argillaceous-ferruginous-siliceous or carbonate one, the fracturing processes occur in the cementation and have an intergranular character.

Such a phenomenon, observed in most of clastic rocks, is present also in flysch sandstones of a scattered structure and siliceous-argillaceous-ferruginous cementation. It is also possible to observe it in the sandstones from Wola Komborska (Fig. 1d).

The *size of grains* predisposes the resistance of a rock, as it affects the critical number of defects leading to the global destabilization of the structure of a rock medium. In fine-grain sandstones, the total loss of resistance is heavily dependent on greater than in coarse-grain rocks number of fractures. Hence, in flysch fine-grain sandstones from Tenczyn Górny (Fig. 2a) the observed resistance is greater than the resistance of coarse-grain sandstones from Barcice regardless of the strengthening participation of the siliceous cementation in the latter (Fig. 2b).

Grains of irregular, complicated geometry either frequently create obstacles to fissure propagation or induce additional processes of corner shearing, which can be observed in the Carpathian carbonate sediments with organic detritus from Leszna Góra (Fig. 2c).

In the Carpathian flysch sandstones the occurrence of irregular grains as well as the remarkable content of carbonates causes only secondary induced processes of the corner shearing. Therefore, when a carbonate material is used as the cementation in sandstones, then the fracturing process may have a mixed inter- and intragranular character, or even transgranular one with possible displacement. The strengthening of the resistance may occur in fissures due to the wedging of rock fragments (Fig. 2d).

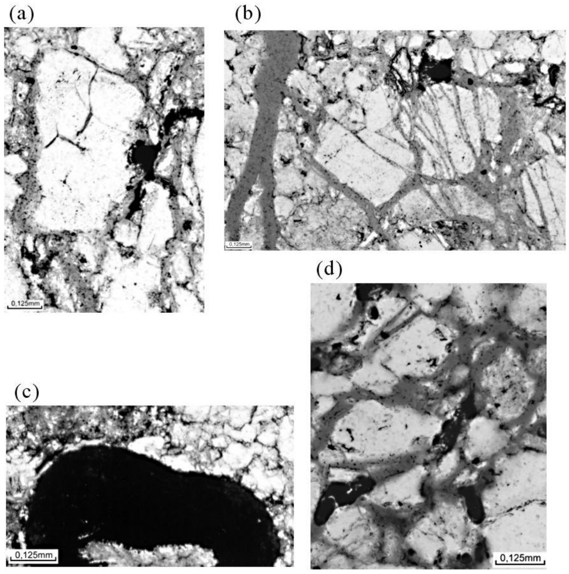

Fig. 2. Examples of fissure development according to the grain size: (a) – coarse-grain flysch sandstone from Barcice, (b) – fine-grain flysch sandstone (from Tenczyn Górny); (c) – modification of fracturing directions in the local grain boundaries – limestones with organic detritus (from Leszna Górna); (d) – wedging of fragments in a fissure; average-grain sandstone with carbonate cementation (from Sobolów)

The process of joining of microfracture focuses into bigger clusters leads to development of macrofractures and global unstable fracturing. The direction of macrofissures can be however locally modified by the anisotropy of the sediment or wedging of bigger rock fragments in the fissure.

The diverse character of mechanisms responsible for destruction of a rock fabric, given by Pinińska (1997, 2000), is the reason for variable dynamics of the fracturing seen on the post-critical branch of the deformation curve in tests of uniaxial compression of sandstone samples (Fig. 3).

The intragranular fracturing in flysch sandstones of a massive structure is illustrated by regular cycles of relaxation and concentration of stresses exposed on the deformation curve certifying the cyclic fracturing of single quartz grains.

The recurrent hysteresis loops displayed on the diagram of acoustic emission are analogous to signals of intensified emission regularly repeated in the time course (Fig. 3a). The frequency of the cycles varies according to the degree of quartz grain sorting. In the case of good sorting of grains, the rock shows characteristics of a repeatable medium. As a result of many cycles, the cohe-

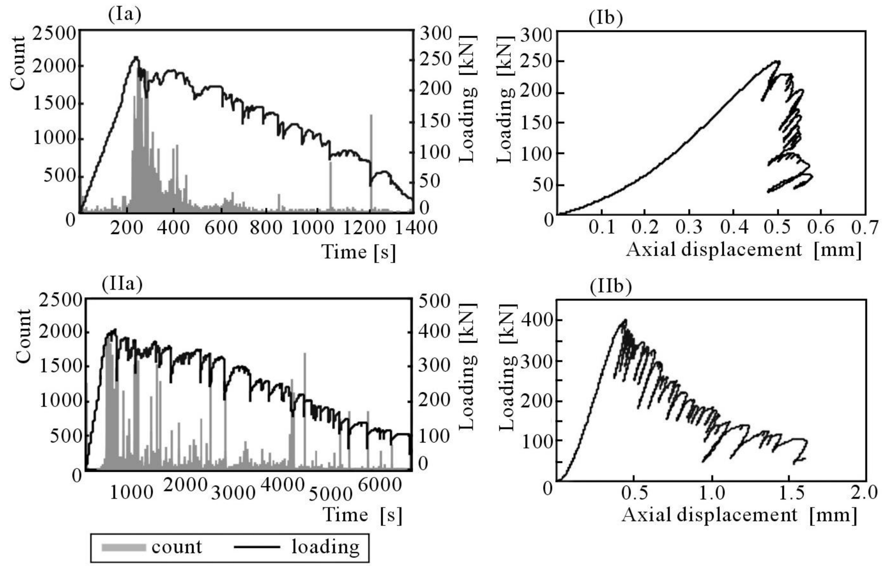

Fig. 3. Results of fracturing registered on the acoustic emission (a) and on the deformation curve (b). I – irregular model (sandstone with carbonate-argillaceous cementation), II – repeatable model (sandstone with siliceous-carbonate cementation)

sive structure of a rock undergoes extensive inside grain destruction without visible changes in the volume. After reaching the critical stage of fracturing, the final split is abrupt and unexpected.

The curves of rock deformation and the course of acoustic emission connected with the intergranular fracturing in sandstones with quartz grains randomly scattered in the weaker carbonate or argillaceous-carbonate cementation illustrate irregular courses of relaxation and concentration of stresses and emitted acoustic signals (Fig. 3b).

Here, the destruction of the rock structure is manifested mostly by the shearing process, hence the registered considerable displacements resulting from the slip. Therefore, it is possible to observe a great scope of residual resistance and considerable postcritical volumetric deformations.

According to the uniaxial compressive test performed on the flysch sandstones with different rock fabrics, not only the rock resistance but also dynamics of losing the stability is strictly related to the granular relations, shape and size of grains. The unstable fracturing of a coarse-grain rock occurs more frequently than in a fine-grain rock as in the latter the unstable fracturing demands more focuses of local fracturing. Thus, the number of oscillations and emission signals characteristic for the moment of destruction of a rock material is, to a great extent, derivative of its granulation. Mechanisms of global fracturing can be blurred only locally by modifications of the direction of microcracks resulting from obstacles on the way of fissure development or wedging of fragments in the dislocation fissure.

The complex fracturing mechanisms, observed in most of the rocks tested under uniaxial compression, are well illustrated by the simulation models of Napier and Peirce (1995) or Malan and Napier (1995) in the case of brittle materials of disordered, polygonal and trygonal structures, where the *Displacement Discontinuity Method* (DDM) was used.

According to the simulations done by Napier and Peirce (1995), the trygonal structures show weaker stability than polygonal ones, which can be explained by the fact that in the trygonal structures there appear large slip zones diagonal to the experimental body. In comparison, the polygonal structures split abruptly with no slip displacements. In each of the presented models, the destabilization of a coarse-grain rock is easier to be attained than in the case of a fine-grain rock.

The deformation mechanisms of the polygonal model refer to the most of crystalline and elastic rocks of repeatable structures with strong quartz grains in their mineral composition. In the case of the analysed flysch sandstones it refers to sandstones of a compact structure with grain/grain contact of quartz grains. The intragranular character of the initial fracturing occuring there is manifested on the deformation curves as regular stress oscillations connected with the local intragranular extension of grains of a special type called the "seed points". In consequence, the destruction of the inner and local structure during transgranular global fracturing results in the final abrupt structure destabilization with absence of volumetric deformations and residual resistance. The locally present wedging of rock fragments in the fissures can cause momentary strengthening of the rock, however this process does not bring considerable volumetric changes either, and the final split is similarly abrupt. The deformation mechanism explained on the model of the trygonal structure, generally charcteristic for carbonate rocks, but also for clastic rocks with considerable content of feldspars or an argillaceous material, refers, in the case of flysch sandstones, to the sediment of a dispersed structure with a considerable content of weak cementation. The intergranular character of such a fracturing process indicates diverse dynamics of the acoustic emission and deformation process. This is connected with the delaying of the fracturing processes by the shearing and slip processes along the coarse edges of the fissure, which results in the considerable post-damage volumetric deformations and long term sustaining of residual resistance.

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Strukturalne uwarunkowania mechanizmów rozciągania i ścinania w skałach fliszu karpackiego

Streszczenie

W skałach fliszu karpackiego poddanych procesowi jednoosiowego ściskania obserwowano zróżnicowane procesy pękania intragranularnego, intergranularnego i transgranularnego. Mechanizmy tych procesów były ściśle zależne od składu mineralnego, struktury i uziarnienia badanej skały. Interpretacji tych powiązań dokonano na podstawie charakterystyk przebiegu ścieżki deformacji, przebiegów emisji akustycznej oraz analizy mikroskopowej spękań w każdej z próbek badawczych. Rezultatem badań jest rozpoznanie czy powstający pod obciążeniem defekt jest wywołany procesem rozciagania, ścinania czy obu tych procesów.

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